SECTION 2.0
WATER QUALITY MONITORING PROGRAMS

The King County Department of Natural Resources currently operates three wastewater treatment plants and one CSO treatment plant which have outfalls that discharge directly into Puget Sound marine waters. The Clean Water Act states that all wastewater collection and treatment facilities that discharge effluent into surface waters are required to have a National Pollutant Discharge Elimination System (NPDES) permit. In Washington, the Washington State Department of Ecology (Ecology) administers this program by delegation from the U.S. Environmental Protection Agency.

An NPDES permit sets limits on the quality and quantity of treated wastewater that is discharged. As part of its NPDES requirements, King County has conducted an extensive point source monitoring program for over 20 years. The purpose of the program is to assess the quality of each facility's effluent, the receiving water around each outfall, and nearby beaches to ensure the facility is meeting the goals of the Clean Water Act. In addition, Washington State's Antidegradation Policy requires that discharges into a receiving water shall not further degrade the existing water quality of the water body.

Water quality may be affected by two types of pollution, point source and nonpoint source. Point source pollution is defined by its entry into the aquatic environment from a specific facility, such as an outfall pipe, and can be generated from a variety of industrial and municipal facilities, such as sewage treatment plants and manufacturing facilities. Nonpoint source pollution comes from any source that is not a point source and includes runoff from streams, groundwater, stormwater, etc. Land use, such as agricultural and urban usage, affects the quality of the runoff. King County's marine monitoring programs are constructed to assess potential effects from both types of pollution and stations are located near point source discharges as well as away from the vicinity of known discharges.

It is essential to observe conditions in areas removed from individual point sources in order to obtain background water quality data. King County has established a marine ambient monitoring program in the Central

Basin of Puget Sound, with stations well removed from the influence of point source discharges. King County's goals for ambient monitoring are to better understand the regional water quality problems, establish priorities for preventative actions, and provide background data needed to identify trends that might indicate impacts from long-term cumulative pollution. An overview of the monitoring programs is provided below and can also be found in Table 2-1.

Table 2-1. Summary of 1997 Monitoring Programs

Sample Location	Matrix	Parameter	# of Stations	
			Ambient	Point Source
Intertidal	Water	Bacteria	15	6
	Sediment	Bacteria	3	3
		Organics[a] & Metals	3	3
	Shellfish	Bacteria	5	3
		Organics & Metals	0	2
	Macroalgae	Metals	0	3
Subtidal	Water	Bacteria	5	5
		General Water Quality Parameters	5	5
	Sediment	Organics & Metals	0	15

[a] Semi-volatile organics, pesticides, and PCBs were monitored.

2.1 AMBIENT AND POINT SOURCE MONITORING PROGRAMS

The ambient and point source monitoring programs focus on both marine waters and their underlying sediments. Many marine pollutants are in particulate form and as these contaminated particles settle to the bottom, pollutant concentrations in the underlying sediments tend to increase.

Most sources of contamination are in nearshore areas and pollutants tend to accumulate in sediments close to these sources. Benthic organisms which live in or on contaminated sediments tend to accumulate these contaminants through contact or ingestion. The now contaminated organism may become prey to animals higher up in the food web, and thus, the concentration of pollutants in organisms tends to increase higher up in the food chain. This process is known as biomagnification. These nearshore areas tend to be high contact areas for both marine organisms and people, therefore, contaminated sediments have an important impact on human and marine environmental health.

Ambient Monitoring

The 1997 ambient monitoring program included sampling and analysis of nearshore and offshore water, sediment, and shellfish tissue (see Table 2-1). Parameters measured included physical properties, such as water clarity and temperature, and nutrients (nitrogen and phosphorous compounds as well as silica). Dissolved oxygen, chlorophyll, and bacteria were also monitored. Organic compounds (e.g., PAHs, pesticides, and polychlorinated biphenyls), metals, and bacteria were monitored in intertidal sediments. Figure 2-1 shows ambient monitoring station locations and Table 2-2 gives a summary of parameters measured at each station. Station coordinates are given in Appendix E.

Point Source Monitoring

King County collected subtidal (offshore) water, sediment, shellfish, and algae samples for the 1997 point source monitoring program. Point source stations include those that are required by the County's NPDES permit (eg., subtidal sediment sites near the West Point Treatment Plant

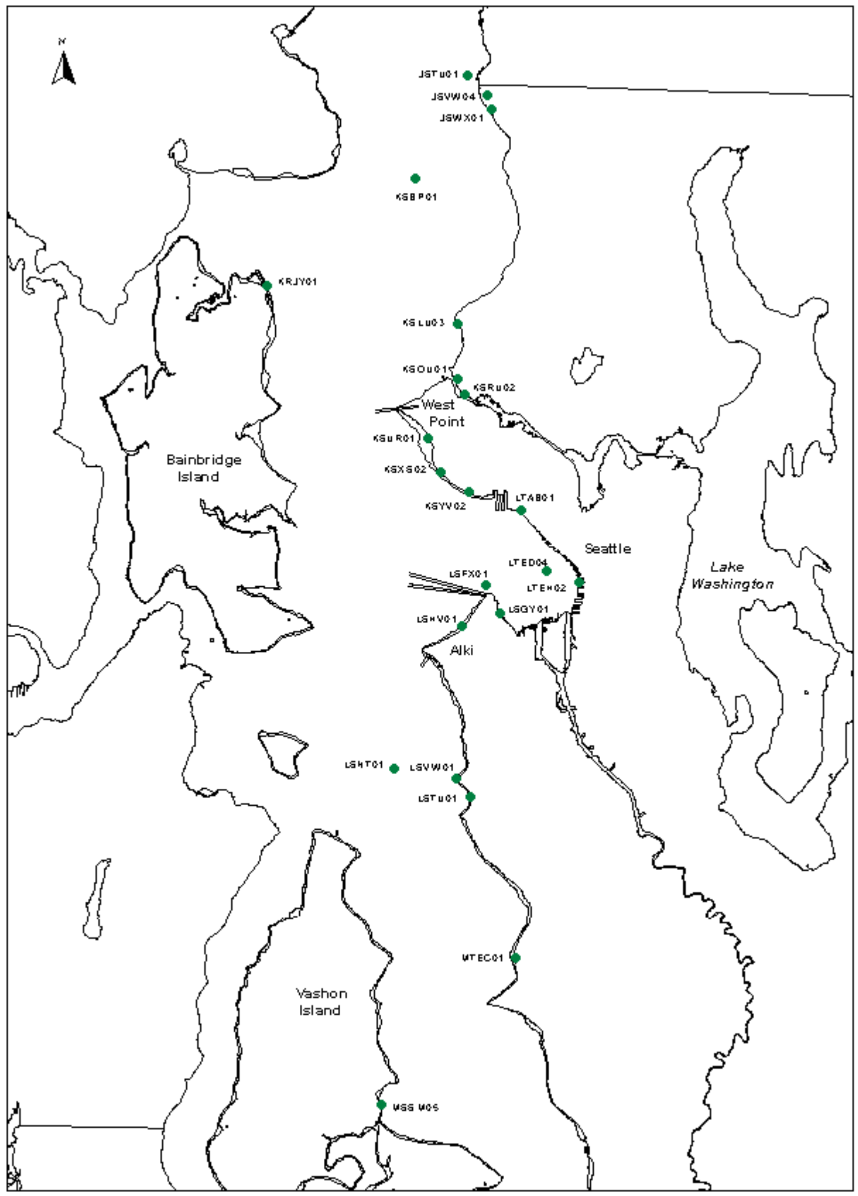

Figure 2-1. Ambient Monitoring Stations

Table 2-2. 1997 Ambient Stations and Parameters Measured

STATION	LOCATION	SUBTIDAL/ INTERTIDAL	SEDIMENT Organics*	SEDIMENT Metals	SEDIMENT Conventionals	SEDIMENT Bacteria	WATER Bacteria	WATER GWQP **	SHELLFISH Bacteria
KSBP01	Point Jefferson	Subtidal					◆	◆	
KSRU02	LW Ship Canal	Subtidal					◆	◆	
LSNT01	Dolphin Point	Subtidal					◆	◆	
JSTU01	Point Wells	Subtidal					◆	◆	
LTED04	Elliott Bay	Subtidal					◆	◆	
JSWX01	Richmond Beach	Intertidal	◆	◆	◆	◆	◆		
JSVW04	Richmond Beach	Intertidal					◆		
KSXS02	Magnolia	Intertidal	◆	◆	◆	◆			
MTEC01	Seahurst Park	Intertidal	◆	◆	◆	◆	◆		◆
KSLU03	Golden Gardens	Intertidal					◆		◆
MSSM05	Tramp Harbor	Intertidal					◆		◆
KRJY01	Fay Bainbridge	Intertidal					◆		◆
KSQU01	Shilshole Bay	Intertidal					◆		
KSYV02	Magnolia	Intertidal					◆		
LTAB01	inner Elliott Bay	Intertidal					◆		
LTEH02	inner Elliott Bay	Intertidal					◆		
LSGY01	Seacrest	Intertidal					◆		
LSFX01	Duwamish Head	Intertidal					◆		
LSHV01	West Seattle	Intertidal					◆		
LSTU01	Lincoln Park	Intertidal					◆		
LSVW01	Fauntleroy Cove	Intertidal					◆		

* Includes semi-volatile organics, pesticides, and PCBs.
** GWQP = general water quality parameters

outfall) and those that are not required but are in close proximity to point sources discharges (eg., intertidal stations near the West Point Treatment Plant). Station locations are presented in Figure 2-2 and station coordinates are provided in Appendix E.

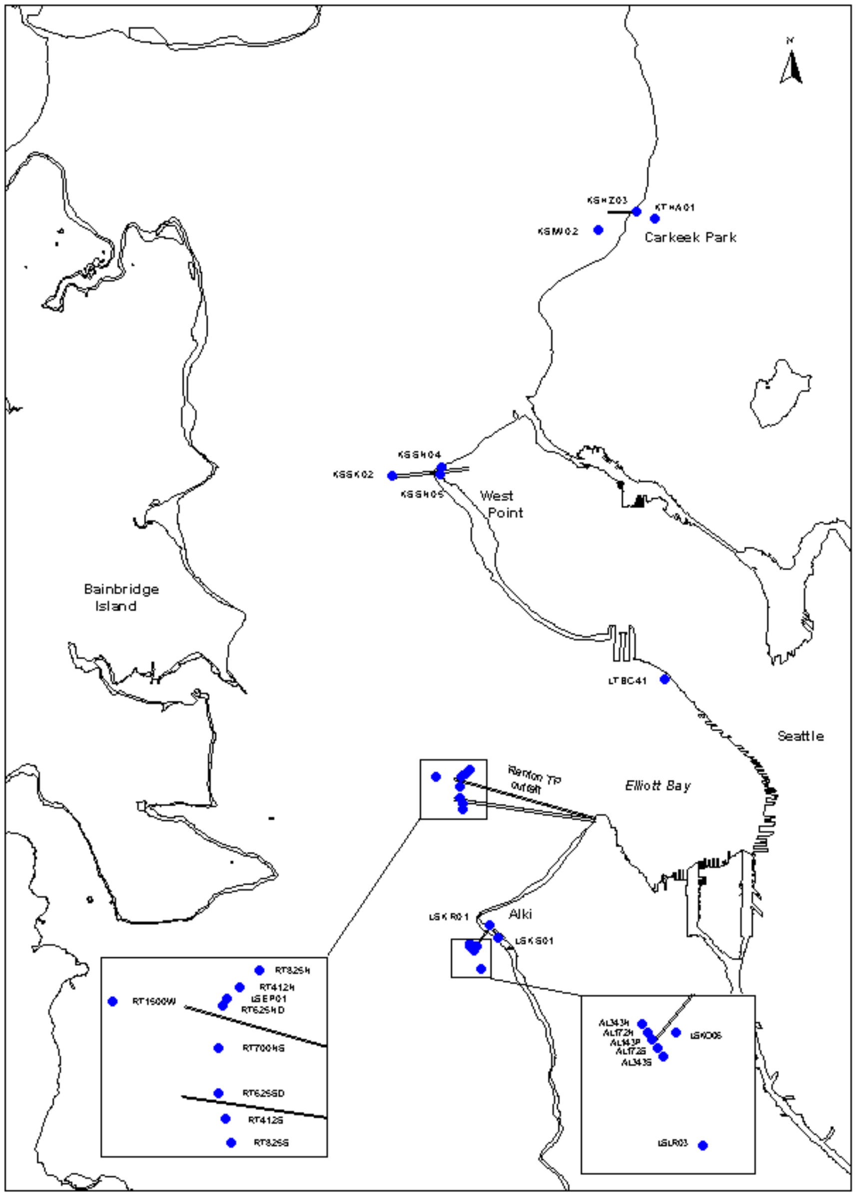

Figure 2-2. Point Source Monitoring Stations

Water was analyzed for bacteria, temperature, salinity, water clarity, dissolved oxygen, nutrients, suspended solids, and chlorophyll. Sediment was analyzed for organic compounds, metals, and conventional parameters (such as total organic carbon, total sulfides, and grain size) (Table 2-3).

Both fecal coliform and *Enterococcus* bacteria were measured in all four matrices. *Enterococcus* is being considered as an indicator of bacterial contamination in marine waters, therefore, both types of bacteria were analyzed in anticipation of potential changes in bacterial monitoring. Although there are no regulatory standards for fecal coliform bacteria in sediment and shellfish tissues, samples were analyzed for informative purposes only.

2.2 WATER COLUMN MONITORING

Water column monitoring is an important component of the County's water quality monitoring programs and is structured to detect natural seasonal changes in the water column as well as identify changes from anthropogenic input. Bacteria are monitored at all sites, and general water quality parameters (temperature, salinity, transparency, dissolved oxygen, chlorophyll-*a*, phaeopigment, ammonia, nitrate+nitrite, total phosphorous, silica, and total suspended solids) are monitored at multiple depths for nine sites. Temperature, salinity, and bacteria are the only parameters measured at KSRU02 located in the Lake Washington Ship Canal.

Bacteria

Biologists and agencies responsible for protecting public health define water quality in terms of several variables, one of those being the presence of bacteria. Fecal coliform bacteria are found in the feces of humans and other warm-blooded animals. These bacteria may enter the aquatic environment directly from humans and animals, from agricultural and storm runoff, and from wastewater. Although fecal coliform bacteria are usually not pathogenic, they may occur along with disease-causing

Table 2-3. 1997 Point Source Stations and Parameters Measured

			SEDIMENT				WATER		SHELLFISH			ALGAE
STATION	LOCATION	SUBTIDAL/ INTERTIDAL	Organics *	Metals	Conventionals	Bacteria	Bacteria	GWQP **	Organics	Metals	Bacteria	Metals
RT825N	Renton outfall	Subtidal	◆	◆	◆							
RT412N	Renton outfall	Subtidal	◆	◆	◆							
RT625ND	Renton outfall	Subtidal	◆	◆	◆							
RT700NS	Renton outfall	Subtidal	◆	◆	◆							
RT625SD	Renton outfall	Subtidal	◆	◆	◆							
RT412S	Renton outfall	Subtidal	◆	◆	◆							
RT825S	Renton outfall	Subtidal	◆	◆	◆							
RT1500W	Renton outfall	Subtidal	◆	◆	◆							
AL343N	Alki Point outfall	Subtidal	◆	◆	◆							
AL172N	Alki Point outfall	Subtidal	◆	◆	◆							
AL143P	Alki Point outfall	Subtidal	◆	◆	◆							
AL172S	Alki Point outfall	Subtidal	◆	◆	◆							
AL343S	Alki Point outfall	Subtidal	◆	◆	◆							
LSLR03	Alki Point outfall	Subtidal	◆	◆	◆							
KSIW02	Carkeek Park	Subtidal					◆	◆				
KSSK02	West Point	Subtidal					◆	◆				
LTBC40	Denny Way	Subtidal	◆	◆	◆		◆	◆				
LSKQ06	Alki Point	Subtidal					◆	◆				
LSEP01	Renton outfall	Subtidal					◆	◆				
KSHZ03	Carkeek Park	Intertidal	◆	◆	◆	◆	◆				◆	
KTHA01	Piper's Creek	Intertidal					◆					
KSSN04	West Point	Intertidal	◆	◆	◆	◆	◆		◆	◆	◆	◆
KSSN05	West Point	Intertidal					◆					◆
LSKS01	Alki	Intertidal					◆					
LSKR01	Alki Point	Intertidal	◆	◆	◆	◆	◆		◆	◆	◆	◆

* Includes semi-volatile organics, pesticides, and PCBs. Organotins were analyzed for subtidal sediments.
** GWQP- general water quality parameters.

bacteria so their presence indicates the potential for pathogenic bacteria to be present. Generally, a high fecal coliform count suggests that there is a greater possibility for pathogenic bacteria to be present. Fecal coliform bacteria are typically found in higher numbers than pathogenic bacteria and are easier and safer to test for in the laboratory.

Regulatory standards have been established for acceptable levels of fecal coliform bacteria for various water uses, including recreation and fish and wildlife habitat. It should be noted, however, that although fecal coliform bacteria are commonly used as an indicator for the presence of pathogens, there are limitations to their use. There is no recognized numerical association between the number of fecal coliform bacteria and the number of pathogens measured in a sample. In addition, the presence of viruses and naturally occurring toxic organisms, such as dinoflagellates, are not indicated by the presence of fecal coliforms and these organisms must be measured independently.

Temperature and Salinity

Water temperature is an important factor in an estuary. As water temperature rises, biological and chemical activity also increases while the capacity of water to hold dissolved oxygen decreases. Water temperature is dependent upon various factors, including depth, season, amount of mixing from tides, wind, storms, amount of freshwater input, and degree of stratification. Both temperature and salinity influence water column stratification, although salinity is more important in determining stratification in estuaries.

Estuaries usually exhibit changes in salinity as freshwater input increases or decreases. Salinity also fluctuates with tides, amount of input of high salinity water from deep Pacific oceanic water, amount of precipitation, and degree of water column mixing from winds. Generally, salinity increases with water depth unless the estuary is well-mixed.

Dissolved Oxygen

Dissolved oxygen concentration is an important factor controlling the presence or absence of estuarine species. Aquatic plants and animals require a certain amount of oxygen dissolved in the water for respiration and basic metabolic processes. Waters that contain high amounts of dissolved oxygen are generally considered healthy ecosystems and are capable of sustaining several species of aquatic organisms.

Several factors can influence dissolved oxygen concentrations, including seasonal influences. As water temperature rises in the spring and summer, the capacity of water to hold dissolved oxygen decreases. In winter, deep oceanic water from the Pacific Ocean containing naturally low levels of oxygen enters Puget Sound. Anthropogenic input and phytoplankton decay may decrease levels of oxygen as bacteria that utilize organic matter for food consume oxygen and the more organic matter present, the more oxygen that is consumed. When this happens, fish and other aquatic organisms may be killed as conditions no longer support marine life.

Transparency

Transparency, or water clarity, is measured to determine the depth to which enough light penetrates to support plant growth. Several factors affect transparency including the amount of suspended silt and soil particles and the amount of phytoplankton and zooplankton in the water column. In addition to transparency, total suspended solids are also monitored. Freshwater input (particularly after storms) and wave action also affect transparency. Low transparency over an extended period of time can degrade the health of a waterbody as the decreased amount of light penetration reduces the area for aquatic plants and primary producers to grow. In addition, many marine organisms feed by filtering water and large amounts of suspended matter may obstruct their filter-feeding systems.

Nutrients

The addition of nutrients, such as nitrate and phosphate, into marine waters can have a considerable effect on the water quality, particularly for nearshore habitats where nutrient input typically occurs and tends to be confined. Nutrients may enter marine waters from wastewater discharges, nonpoint runoff, and from riverine and oceanic sources. The greatest impact these nutrients may have is the sudden increase in aquatic plants, in terms of biomass.

The amount of light that can penetrate the water column and the amount of nutrients in the water affect phytoplankton growth. Nitrogen is the primary nutrient that controls or limits the growth of phytoplankton in marine waters (Valiela, 1984). Although nitrogen occurs naturally in the marine environment, abnormal increases from sources such as wastewater or fertilizers can cause significant increases in phytoplankton growth. An increase in phytoplankton biomass may cause a decline in dissolved oxygen as the phytoplankton cells respire and decay. This depression in dissolved oxygen levels can become critical in areas of reduced circulation. The marine waters within King County have not experienced any significant eutrophication problems, mainly due to the high degree of mixing in the central basin of Puget Sound (PSWQAT, 1998).

Nitrogen Compounds Nitrate, nitrite, and ammonium are forms of inorganic nitrogen used by phytoplankton in the aquatic environment. Nitrates and nitrites are formed through the oxidation of ammonium by nitrifying bacteria. Nitrogen, in its various forms, is usually the limiting nutrient in marine waters. Therefore, an increase in nitrogen compounds could lead to phytoplankton blooms. When blooms occur, water conditions (such as reduced water clarity and dissolved oxygen) may become unfavorable for aquatic organisms. Input of nitrogen compounds may originate from sources such as wastewater from municipal discharges and agricultural runoff.

Phosphorous Phosphorous is an essential element for aquatic plants and a fundamental element in the metabolic process for both plants and animals. Total phosphorous includes both organic phosphorous and inorganic phosphate. Inorganic phosphates are rapidly taken up by algae and other aquatic plants, although phosphates are usually not the limiting nutrient in marine waters. However, large inputs could cause algal blooms which could lead to unfavorable conditions. Sources of phosphorous potentially entering the marine environment include wastewater from municipal discharges, industrial wastes, nonpoint agricultural runoff, rivers and streams, and the Pacific Ocean.

Silica Silica is a micronutrient needed by diatoms, radiolarians, some sponges and other siliceous organisms for skeletal growth. Silica can be used as an indicator of plankton blooms, along with chlorophyll *a*, as silica concentrations will decrease in the photic zone from an increase in phytoplankton uptake. Sediments act as a sink for silica which may be regenerated by various physical and biological processes and reused by organisms on the seafloor and in overlying waters.

Chlorophyll and Pheopigments

Chlorophyll *a* is the most direct indicator of phytoplankton biomass since all marine planktonic algae contain this photosynthetic pigment. However, chlorophyll *a* concentrations are not an exact assessment of phytoplankton abundance. The ratio of phytoplankton biomass to chlorophyll varies with species, nutritional status, and environmental conditions. Pheopigments, such as pheophorbide *a* and pheophytin *a*, are degradation products of chlorophyll and are produced when phytoplankton cells are grazed upon by zooplankton. High concentrations of pheopigments relative to chlorophyll *a* indicate a high level of grazing in an aquatic ecosystem. Several factors influence phytoplankton abundance, including amount of solar radiation, extent of grazing, water temperature, nutrient availability, and water column stratification.

Water Column Sampling Methods

Field Methods

Subtidal water column samples were collected in accordance with the *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissues in Puget Sound* (PSEP, 1996) by the King County Environmental Services Section. A brief description is provided below.

Subtidal water samples were collected using the R/V Liberty, a 42-ft boat, equipped with a hydraulic crane on the rear-deck. Deep water samples were collected by mounting 5-liter Niskin bottles at specified depths on a weighted hydro-wire and lowering the bottles using a hydraulic boom. Once the bottles were in place, the boom operator initiated the tripping sequence by attaching and releasing a messenger on the wire. Bottles were then retrieved and samples immediately placed into sample containers. Dissolved oxygen samples were immediately preserved with a minimum of 2 milliliters (mls) of $MnSO_4$ (manganous sulfate) and 2 mls of AIA (alkali iodide azide), then stored in the dark. With the exception of dissolved oxygen bottles, sample containers were stored on ice until delivered to the laboratory.

Transparency (water clarity) measurements were collected using an 8-in. black-on-white secchi disk. Secchi depths were recorded to the nearest 0.5 meter. As readings may vary depending upon environmental conditions (e.g., waves and glare) and the individual, all field crew were trained to collect measurements using the same procedure. Temperature measurements were obtained with a digital thermometer and recorded to the nearest tenth degree Celsius (^{o}C).

Intertidal water samples were collected by inverting a polyethylene bottle just below the water surface and then capping the bottle before removing the container. Samples were collected from approximately knee-deep water when possible. At some sites where accessibility is difficult, such as LTAB01, samples were collected with a container lowered on a rope and then transferred into the sample container.

Laboratory Methods

With the exception of temperature and secchi disk transparency which were measured in the field, all water column parameters were analyzed at the King County Environmental Laboratory. Laboratory methods and detection limits are provided in Table 2-4.

Table 2-4. Laboratory Methods and Detection Limits for General Water Quality Parameters

Parameter	Units [1]	MDL [2]	RDL [3]	Method [4]
Salinity	psu	0.005	0.01	SM2520-B
Dissolved oxygen	mg/L	0.5	1	SM4500-O-B
Chlorophyll-*a*	mg/m^3	0.01	0.05	SM10200-H
Phaeophytin	mg/m^3	0.01	0.05	SM10200-H
Ammonium-nitrogen	mg/L	0.02	0.04	SM4500-NH3-H
Nitrite + Nitrate -nitrogen	mg/L	0.05	0.1	SM4500-NO3-F
Total phosphorous	mg/L	0.005	0.01	SM4500-P-B,E
Total suspended solids	mg/L	0.5	1	SM2540-D
Silica	mg/L	0.05	0.1	SM4500-SI-D

[1] psu = practical salinity units
mg/L = milligram per liter
mg/m^3 = milligram per meter cubed
[2] MDL = method detection limit
[3] RDL = reported detection limit
[4] APHA 1992

Fecal coliform and *enterococcus* bacteria were analyzed according to Standard Methods 9222D and 9230C, respectively (APHA, 1992).

All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and spikes where appropriate. All data were reviewed prior to entry into the LIMS (Laboratory Information Management System) database.

2.3 SEDIMENT MONITORING

Sediment monitoring is a component of the County's ambient and point source monitoring programs as pollutants (organics and trace metals) tend to be associated with particles that settle out onto bottom sediments. At sufficient concentrations, these compounds may be harmful to benthic organisms and may be bioaccumulated. Conventional parameters, such as total organic carbon, total solids, total volatile solids, grain size distribution, and total sulfide are also monitored as these parameters affect the bioavailability and or/toxicity of pollutants as well as influence the concentration of pollutants accumulated. A more detailed description of why conventional parameters are measured is provided below.

Total Solids

Total solids are the inorganic and organic particles remaining after a sediment sample has been dried. This parameter is measured in order to convert chemical concentrations from a wet weight to a dry weight basis.

Total Volatile Solids

Total volatile solids are the fraction of total solids that are lost on ignition at a high temperature. This value is used as an estimate of the amount of organic matter in the solids portion.

Grain Size Distribution

This is a measure of the size range of particles contained in a given sample. Grain size is usually separated into four main categories: silt, clay, sand, and gravel. Grain size has an influence on chemical concentrations found in sediments and sediments with a large proportion of small particles (silt and clay) tend to have higher chemical concentrations.

Total Organic Carbon

This is a measure of the total amount of particulate and nonparticulate organic carbon contained in a sample. In the same manner as grain size, total organic carbon also has an influence on chemical concentrations contained in sediments. The higher the organic carbon content, the higher chemical concentrations tend to be. This is particularly true for organic compounds.

Total Sulfides

Total sulfides represent the amount of all sulfide compounds in a given sample. Sulfides are formed by the anaerobic breakdown of organic matter and are measured as they may be toxic to some benthic organisms at low concentrations and can create unaesthetic conditions.

Methods

Field Methods

Subtidal sediment samples were collected by the King County Environmental Services Section using the R/V Liberty, a 42-foot boat equipped with a hydraulic crane on the rear-deck. Samples were collected with two stainless steel 0.1-m^2 van Veen grab samplers deployed in tandem. The sampler was decontaminated between sites by scrubbing with a brush to remove excess sediment, followed by an on-board rinsing and thorough in-situ rinsing. If the sample acceptability criteria were met, the top two centimeters of sediment from a minimum of five subsamples were composited and homogenized before transference to the appropriate sample containers. Sediment samples were collected in accordance with the Puget Sound Estuary Program (PSEP) recommended protocols (PSEP, 1996) and the County's *Standard Protocol for Marine Sediments* (King County, 1997c).

Intertidal samples were collected by hand-held core tubes. Once the required sample amount was obtained, sediments were homogenized in a stainless steel bowl before being transferred to appropriate sample containers. All sampling equipment was site specific and not reused and all samples were stored on ice until submitted to the laboratory.

Laboratory Methods

All parameters were analyzed by the King County Environmental Laboratory with the exception of particle size distribution and total sulfide. These two analyses were performed by a subcontract laboratory. Methods and detection limits are provided in Table 2-5. All metals were analyzed using inductively coupled plasma (ICP) emission spectrometry with the exception of mercury. Mercury was analyzed by cold-vapor atomic absorption spectrophotometry. Semivolatile organics were extracted with an organic solvent and then analyzed by gas chromatography/mass spectrometry (GC/MS). Pesticides and PCBs were extracted with organic solvents and then analyzed using a gas chromatograph equipped with an electron capture detector (ECD).

All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and surrogates and spikes where appropriate. All data were reviewed prior to entry into the LIMS database.

2.4 SHELLFISH AND ALGAE

Biota monitoring is a component of the County's ambient and point source monitoring programs since contaminants may be bioaccumulated by shellfish and algae. Clam tissues are monitored for organic and metal contaminants and bacteria (fecal coliform and *enterococcus*) as these measurements provide an indication of potential impacts to both shellfish and to humans that consume them. Percent lipids in shellfish are also monitored as this parameter affects the concentration of organic pollutants accumulated.

Table 2-5. Laboratory Methods and Detection Limits for Sediments

Parameter	Units	MDL	Method
Total solids	%	0.005	SM2540-G
Total volatile solids	%	0.005	SM2540-G
Total oil & grease	mg/kg	100	SM5520-B
Total organic carbon	mg/kg	5	SM5310-B
Total sulfide	mg/kg	10	SM4500-S
Trace metals, total, ICP	mg/kg	variable [1]	Metro 16-02-004
Mercury, total, CVAA	mg/kg	0.019	Metro 16-01-001
Semivolatile organics	µg/kg	variable [1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable [1]	SW 846 8080
Organotins	µg/kg	0.3	NOAA, 1989
Grain size distribution	%	---	PSEP, 1991
Fecal coliform bacteria	MPN/100g	20	Metro MC SOP 6.1.3
Enterococcus bacteria	MPN/100g	20	Metro MC SOP 6.3.3

[1] Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendix B.

Algae are monitored for metals as it is well documented that algae absorb metals directly from seawater (Phillips, 1994; Hou and Yan, 1998). It is difficult to measure metals in seawater, therefore, algae are used as a biomonitor to assess metal concentrations near intertidal areas.

Methods

Field Methods

Shellfish samples were collected by the King County Environmental Services Section. Clams from each sampling station were collected by digging with shovels in the vicinity of siphon holes. A tarp was placed next to the digging site and excavated sediment was placed on the tarp to minimize disturbance to other organisms. The sediment was replaced after clams of sufficient size were removed. After the required amount of shellfish were obtained, the clams were placed in watertight plastic bags and stored on ice until delivered to the laboratory. Clams collected for metals and organics analyses were wrapped in aluminum foil prior to placement in plastic bags. Dependent upon the species collected, a minimum of five clams were collected for each composite sample. For native littleneck clams, a minimum of 20 clams were collected in order to obtain the necessary amount of tissue for analysis.

Algae samples were collected by the King County Environmental Services section. Algae samples, composed entirely of *Ulva fenestrata*, were collected in glass jars and consisted of only attached healthy algae (i.e., discolored or free-floating algae were not collected). It is the sampling policy to collect only the most prevalent edible algae wherever possible, and there was sufficient *Ulva fenestrata* at all the sampling stations to adhere to this policy. After the required amount of algae were obtained, the jars were stored on ice until delivered to the laboratory.

Laboratory Methods

Shellfish samples were processed in accordance with PSEP recommended protocols (PSEP, 1996). Before the clams were opened, the shells were cleaned with a brush and tap water to remove sand and other material adhering to the shells. The shells were then given a final rinse with deionized water. Tissues from each clam were removed with stainless steel scalpels, composited along with the liquor, and then homogenized with a stainless steel blender. Samples were then frozen until analyzed with the exception of the sample portion removed for fecal coliform analysis. The fecal coliform and *enterococcus* analyses were initiated immediately following processing.

Algae samples were processed at the King County Environmental Laboratory. Algae were rinsed with deionized water to remove sand and other material adhering to the blades. Sample portions obtained for each station were processed in a stainless steel blender. Samples were then frozen until analyzed.

All shellfish and algae parameters were analyzed by the King County Environmental Laboratory. Methods and detection limits are provided in Table 2-6. All metals were analyzed using ICP emission spectroscopy with the exception of mercury. Mercury was analyzed by cold-vapor atomic absorption spectrophotometry. Semi-volatile organics were extracted with an organic solvent and then analyzed by GC/MS. Pesticides and PCBs were extracted with organic solvents and then analyzed using a GC equipped with an ECD. Bacteria samples were processed within eight hours of sample collection and analyzed by multiple-tube fermentation technique.

All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and surrogates and spikes where appropriate. All data were reviewed prior to entry into the LIMS database.

Table 2-6. Laboratory Methods and Detection Limits for Shellfish and Algae

Parameter	Units	MDL	Method
Total solids	%	0.005	SM2540-G
Total lipids	%	0.1	KCEL OR 07-01-001
Trace metals, total, ICP	mg/kg	variable [1]	KCEL 16-02-003
Mercury, total, CVAA	mg/kg	0.004	KCEL 16-01-003
Semivolatile organics	µg/kg	variable [1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable [1]	SW 846 8080
Fecal coliform bacteria	MPN/100g	20	KCEL MC 6.1.2
Enterococcus bacteria	MPN/100g	20	KCEL MC 6.3.2

[1] Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendix C.

2.5 REGULATORY STANDARDS

Regulatory standards and guidelines for water quality have historically focused on those parameters that are of concern to human health. As a result, monitoring programs and criteria were concerned with bacteriological characteristics of surface waters. The focus of water quality guidelines has expanded to include the health of aquatic organisms since the widespread use of pesticides, industrial and commercial uses of the Seattle waterfront, and the overall increase in concerns about water quality in Puget Sound. Washington State has implemented water quality standards for both surface waters and marine sediments.

The use of bacterial indicators and criteria for pollutants is necessary in order to evaluate data obtained from monitoring programs. Water quality management decisions are then based upon these findings. In addition to their use as assessment tools, environmental quality guidelines provide a basis for the development of site-specific water quality objectives for environmental contaminants. These guidelines may also be used to identify the need for source controls to reduce the input of contaminants into marine waters.

The EPA has established nationwide water quality criteria for specific pollutants, such as trace metals and PAHs. The priority is on those pollutants that show immediate toxic effects or have the potential to accumulate in the food chain. The Clean Water Act requires the State to adopt federal water quality criteria or promulgate their own standards which afford equal or better protection to sensitive organisms.

Washington State Standards for Pollutants

Fecal Coliform Bacteria Standards

Washington State divides surface water uses into five classes for both marine and freshwater: AA, A, B, C, and Lake. Bacteria concentrations in samples taken from marine waters for both the ambient and point source monitoring programs are compared with the Class AA marine water standard and freshwater samples are compared to the Class AA freshwater standard (Table 2-7).

The state fecal coliform standards are expressed as geometric mean values. The reason for this is due to the high variability in fecal coliform counts as bacteria tend to multiply exponentially. This variability can be reduced by transforming the data using natural logarithms. This reduces the apparent differences between very high and very low numbers and also simplifies plotting the data by numerically compensating for the exponential growth rate of bacteria. Sample results obtained for King County's monitoring programs are expressed as a moving geometric mean to facilitate comparisons with state bacteria standards. This value is obtained by taking the geometric mean value for the 30 most recent samples (as directed by the National Shellfish Sanitation Program guidelines for systematic random sampling).

Table 2-7. Fecal Coliform Bacteria Standards (colonies/100 ml)

Class	Moving Geometric Mean[a]	Peak[b]	Comments
AA: Freshwater Marine	50 14	100 43	Exceptional quality suitable for water supply (domestic, industrial, and agricultural), stock watering, fish and shellfish, recreation, and wildlife habitat.
A: Freshwater Marine	100 14	200 43	Can be used for the same purpose as Class AA, but differs in the allowed maximum temperature, minimum level of dissolved oxygen, and pH.
B: Freshwater Marine	200 100	400 200	Listed as "good"; it can be used for industrial and agricultural water supply and secondary contact recreation.
C: Both	200	400	Listed as "fair"; it can be used for industrial water supply, fish migration, secondary contact recreation, commerce, and navigation.
Lake	50	100	Meets or exceeds the requirements for all or substantially all uses listed for Class AA waters.

[a] Geometric mean of the 30 most recent samples.

[b] Not more than 10 percent of the 30 most recent samples may exceed this value.

Source: WAC 173-201a, November 25, 1992; NSSP, 1995.

As well as the moving geometric mean standard, no more than 10 percent of the samples used to obtain the moving geometric mean value may exceed a defined upper limit (see Table 2-7). For the Class AA marine water standard this value is 43 colonies/100 ml and 100 colonies/100 ml for the freshwater Class AA standard.

Computing Geometric Means. Each geometric mean is calculated by taking the sum of the natural logarithms of the sample values, dividing that number by the number of samples, and then taking the inverse natural logarithm. The formula is given below:

$$\text{geometric mean} = \text{antilog}\ \frac{1}{n}\Sigma \log Y$$

where n equals the number of fecal coliform observations and Y equals an individual observation (colonies/100 ml).

Fecal coliform levels below the method detection limits (MDL) are reported as <MDL. In order to calculate geometric means, any value reported as <MDL was assumed to be one.

The moving geometric mean is calculated by taking the results of the 30 most recent samples and applying the formula shown above. When a new value is determined, it becomes part of the moving mean and the oldest value is dropped.

Sediment Standards

Contaminants may occur in sediments as part of the natural environment, however, it is more likely that sediments become contaminated by industrial and municipal discharges and non-point sources. Sediment quality guidelines provide a means of assessing sediment quality which leads to informed management decisions regarding the sediments and overlying waters.

Several studies conducted in Puget Sound have found sediments that are contaminated with pollutants such as petroleum hydrocarbons, PAHs, PCBs, and metals. Several of these contaminated sites have been associated with adverse effects on the fish and shellfish that come into contact with these compounds.

In 1991, Ecology promulgated the Sediment Quality Standards (SQS) which contain numeric criteria for specific organic and metal compounds (Table 2-8). The standards specify, based on the best available knowledge, the levels of sediment contaminants at which no adverse effects to marine organisms are expected. These standards are derived from the Puget Sound Apparent Effects Thresholds (AETs) for selected compounds, which are based on biological testing results (EPA, 1988). Concentrations of compounds that do not exceed the SQS values are expected to have no long-term adverse effects on marine biological resources. Ecology is currently developing SQS that protect human health.

The standards for ionizable organic compounds and metals are presented on a dry weight basis (the wet weight concentration divided by the decimal fraction of the total solids value) while the nonionizable organic compounds are organic carbon normalized.

Why Sediment Data Are Organic Carbon Normalized. The presence of contaminants in sediments does not necessarily indicate that the sediments are toxic to marine organisms. An important factor to the toxicity of contaminants is how much of a toxic compound is available for uptake directly into an organism or accumulated through the food chain.

In general, organic compounds, which make up the largest class of chemicals of concern, tend to become associated with the organic matter contained in sediments. The nonpolar, nonionizable organic compounds (such as chlorinated hydrocarbons, aromatic hydrocarbons, and phthalates) have a tendency to adhere to organic matter in water and sediments whereas substances that form ions (such as salts, acids, bases, phenols, and metals) dissolve in water.

Table 2-8. Washington State Marine Sediment Management Standards

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Metals	mg/kg dry weight	
Arsenic	57	
Cadmium	5.1	
Chromium	260	
Copper	390	
Lead	450	
Mercury	0.41	
Silver	6.1	
Zinc	410	
Nonionizable Organic Compounds	mg/kg organic carbon	µg/kg dry weight
Total LPAHs [a]	370	5200
Naphthalene	99	2100
Acenapthylene	66	1300
Acenapthene	16	500
Flourene	23	540
Phenanthrene	100	1500
Anthracene	220	960
2-Methylnaphthalene	38	670
Total HPAHs [b]	960	12000
Fluoranthene	160	1700
Pyrene	1000	2600
Benzo(*a*)anthracene	110	1300
Chrysene	110	1400
Total Benzofluoranthenes	230	3200
Benzo(*a*) pyrene	99	1600
Indeno(1,2,3-*c,d*)pyrene	34	600
Dibenzo(*a,h*)anthracene	12	230
Benzo(*g,h,i*)perylene	31	670

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Nonionizable Organic Compounds	mg/kg organic carbon	µg/kg dry weight
1,2-Dichlorobenzene	2.3	35
1,4-Dichlorobenzene	3.1	110
1,2,4-Trichlorobenzene	0.81	31
Hexachlorobenzene	0.38	22
Dimethyl phthalate	53	71
Diethyl phthalate	61	200
Di-n-butyl phthalate	220	1400
Butyl benzyl phthalate	4.9	63
Bis (2-ethylhexyl) phthalate	47	1300
Di-n-octyl phthalate	58	6200
Dibenzofuran	15	540
Hexachlorobutadiene	3.9	11
N-Nitrosodiphenylamine	11	28
Total PCBs	12	130
Ionizable Organic Compounds	mg/kg dry weight	
Phenol	0.42	
2-Methylphenol	0.063	
4-Methylphenol	0.67	
2,4-Dimethylphenol	0.029	
Pentachlorophenol	0.36	
Benzyl alcohol	0.057	
Benzoic acid	0.65	

[a] Represents the sum of the following low molecular weight PAHs: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, and Anthracene.

[b] Represents the sum of the following high molecular weight PAHs: Fluoranthene, Pyrene, Chrysene, Benz(*a*)anthracene, Benzo(*a*)pyrene, total Benzofluoranthenes, Indeno(1,2,3-*c,d*)pyrene, Dibenzo(*a,h*)anthracene, and Benzo(*g,h,i*)perylene.

Source: Ecology, 1995

Organic matter in sediments is a food source for many benthic organisms (organisms that live on or near bottom sediments). Too little organic matter will not support these organisms and too much will reduce the number due to natural toxic effects associated with microbial activity. The organic carbon content of sediments has been shown to be related to the bioavailability and toxicity of some organic compounds to aquatic organisms (Di Toro et al., 1991).

The toxicity of organic compounds in sediments appears to be more closely correlated to the concentration of organic carbon in the sediments rather than the dry weight concentration. Thus, a more accurate measure of contaminant toxicity can be assessed if the data are "normalized" for the total organic carbon (TOC) content. For this reason, the State standards for nonionizable organics are based upon concentrations that have been TOC normalized (Michelson, 1992). Organic carbon normalization is achieved by dividing the dry weight concentration by the decimal fraction of TOC content. However, when TOC values are very low (e.g. <0.2 %) it is not appropriate to normalize contaminant values, as even background levels may exceed regulatory standards. When the TOC content is less that 0.2%, dry weight values are more appropriate to use than organic carbon normalized values.

Biota Standards

In addition to contaminants found in water and sediment, several contaminants have the potential to accumulate in the tissues of aquatic biota, such as fish and shellfish. Bioaccumulation in biota may affect not only the species directly accumulating the contaminants, but humans and other species that consume the affected species. Numerical tissue-residue guidelines provide a basis for assessing the hazards that tissue-laden contaminants pose to human health and wildlife, and therefore, a basis for regulating contaminant inputs into the environment. Ecology does not currently have tissue-residue standards. However, fecal coliform concentrations in shellfish samples were compared with guidelines used by the Washington State Department of Health.

Water Standards

Washington State currently has marine surface water quality standards for several contaminants, including metals, pesticides, and PCBs. These standards were derived for the protection of a variety of uses, including human health and the propagation and protection of fish, shellfish, and wildlife. Water quality standards for these compounds are not provided in this report as they were not sampled for the ambient or point source monitoring programs. However, the standards may be obtained from the Washington Department of Ecology and are also available on their website at http://www.wa.gov/ecology/wa/standards.